NASA/TM—2006-214345

Static and Switching Characteristics of a 4H-SiC Based BJT to 200 °C

Janis M. Niedra
QSS Group, Inc., Cleveland, Ohio

Gene E. Schwarze
Glenn Research Center, Cleveland, Ohio

July 2006

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to *help@sti.nasa.gov*

- Fax your question to the NASA STI Help Desk at 301–621–0134

- Telephone the NASA STI Help Desk at 301–621–0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076–1320

NASA/TM—2006-214345

Static and Switching Characteristics of a 4H-SiC Based BJT to 200 °C

Janis M. Niedra
QSS Group, Inc., Cleveland, Ohio

Gene E. Schwarze
Glenn Research Center, Cleveland, Ohio

Prepared for the
International Conference on High Temperature Electronics (HiTEC 2006)
cosponsored by IMAPS, Sandia National Laboratories, Jet Propulsion Laboratory, and the Air Force Research Laboratory, WPAFB
Santa Fe, New Mexico, May 15–18, 2006

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

July 2006

Acknowledgments

This work was sponsored by the NASA Glenn Research Center under NAS3–00145. The authors thank Philip Neudeck of NASA Glenn for valuable technical suggestions.

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076–1320

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Available electronically at http://gltrs.grc.nasa.gov

Static and Switching Characteristics of a 4H-SiC Based BJT to 200 °C

Janis M. Niedra
QSS Group, Inc.
Cleveland, Ohio 44135

Gene E. Schwarze
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

Static curves and resistive load switching characteristics of a 600 V, 4 A rated, SiC-based NPN bipolar power transistor (BJT) were observed at selected temperatures from 23 to 200 °C. All testing was done in a pulse mode at low duty cycle (~0.1 percent).

Turn-on was driven by an adjustable base current pulse and turn-off was accelerated by a negative base voltage pulse of either 7 or 0.6 V.

Switching observations were done at base drive currents (I_B) up to 400 mA and collector currents (I_C) up to 4 A, using a 100 Ω non-inductive load. At I_B = 400 mA and I_C = 4 A, turn-on times typically varied from 81 to 97 ns, over temperatures from 23 to 200 °C. As expected, lowering the base drive greatly extended the turn-on time. Similarly, decreasing the load current to I_C = 1 A with I_B = 400 mA produced turn-on times as short as 30 ns. Over the 23 to 200 °C range, with I_B = 400 mA and I_C = 4 A, turn-off times were in the range of 61 to 77 ns with the 7 V sweep-out and 130 to 150 ns with the 0.6 V sweep-out. At a fixed temperature and I_C, the turn-off time decreased slightly with decreasing I_B, for I_B sufficient to still provide full turn-on.

The ratio of conduction to switching losses is estimated, based on the observed I_C transition times and static curves. An estimate at 200 kHz and a 50 percent duty cycle shows that under practicable conditions the two losses can be comparable. Hence the evidence obtained does not support the occasionally voiced concern of necessarily unacceptably high conduction losses in SiC-based BJTs.

Introduction

Compared to silicon (Si), silicon carbide (SiC) is an attractive material for power switches operating at high temperature, high voltage and high power density because of its wide band-gap, high thermal conductivity and high breakdown electric field strength. Today, Si BJTs are not considered to be competitive for two main reasons. First, BJTs are current controlled devices, which require substantial base drive current. Compared to power MOSFETs and IGBTs, which are voltage-controlled devices, this feature of BJTs complicates the drive circuits and also leads to increased power dissipation. Second, Si BJTs suffer from the "second breakdown" avalanche effect, which can lead to catastrophic switch failure. However, as shown by Huang and Zhang (ref. 1), the critical current density in SiC to cause "second breakdown" is more than two orders of magnitude greater for a SiC npn BJT than for a Si device. However, a general advantage of BJTs is that they avoid many of the problems of the gate oxide of MOSFETs and IGBTs, such as oxide reliability at high temperature and high fields and low inversion layer mobility at the oxide/semiconductor interface.

SiC npn BJTs have a short minority carrier lifetime in the p-type base (ref. 2). This is advantageous for high frequency switch operation, but detrimental to the common emitter dc current gain β. Because BJTs are current driven and require a continuous base current for control, it is critical to have high β at high collector currents. Therefore, improving the β of SiC BJTs is very important and recently considerable progress has been made in improving it, along with current density and blocking voltage. The first BJT reported in 6H-SiC in 1977 (ref. 3) had β = 4, but in 1993 Palmour et al. (ref. 4) reported an increase in β to 10.4. Since then, several investigators have reported considerably improved current gains, using 4H-SiC. Ryu et al., [5] in 2001 reported a β = 20 at I_C = 2.7 A, and V_{CE} = 2 V for a BJT capable of blocking 1800 V. In 2004, Zhang et al., (ref. 6) demonstrated a β = 47 for I_C = 4.7 A, a J_C = 392 A/cm^2 and V_{CE} = 6.5 V. In 2005, Krishnaswami, et al., (ref. 7) reported a high voltage, high current (1000 V/30 A) BJT with β = 14.

The objective of the experimental work reported in this paper was to investigate the effect of temperature (23 to 200 °C) on the static and dynamic characteristics of 4H-SiC BJTs fabricated for NASA by United Silicon Carbide, Inc. The upper test temperature limit of 200 °C was set by the packaging materials. The test voltages for the dynamic switching tests ranged from 100 V for a collector current of 1 A to 400 V for a 4 A collector current and β_{max} = 20. The special test circuits developed to measure the dynamic characteristics of the 4H-SiC BJT are also briefly discussed.

Static Collector-to-Emitter Curves

The 4H-SiC based NPN BJT tested was selected from a group of similarly performing devices. The static curves at 23 and 200 °C presented in figure 1 were captured by a Tektronix model 370B programmable curve tracer, using a 20 mA base step (pulsed) up to 10 steps.

Figure 1 shows that the static characteristics at 23 and 200 °C of this BJT are not significantly different, suggesting that the device may be suitable for high temperature operation as a power switch. Curves taken at selected intermediate temperatures were likewise similar. This known behavior (ref. 4) is in stark contrast to the collapsing of characteristics with increasing temperature reported for SiC-based SITs (ref. 8). When going from 25 to 200 °C and at a gate voltage of 5 V, the drain current of those SITs collapsed by a factor of 5! The saturated on-resistance is seen to be of the order of 2 Ω at 23 °C and 1.5 Ω at 200 °C.

Testing Circuits

A constant voltage source feeding a resistive load in the collector circuit was chosen to make up a simple power side of the circuit. A nearby charged capacitor served well as the power source, since operation was with sub-microsecond pulses at no more than 0.1 percent duty cycle. The BJT itself was mounted to a temperature-controlled boron nitride plate, with a thermocouple attached directly to the BJT. A general circuit diagram is provided in figure 2.

A fast rise, high voltage pulser is suitable for providing a very fast-rise current pulse to the base of a BJT. The DEI model HV-1000 is capable of pulse heights up to 850 V into a 50 Ω load at a low duty cycle, with a rise-time of 10 ns and durations up to 10 μs. Figure 3 shows the basic arrangement, omitting the required external high voltage supply and trigger pulser. Since the forward V_{BE} is only of the order of 10 V, good quality current pulses can be obtained into the base of the BJT. The duty cycle can be set as low as one pleases and about 0.1 percent was used, with a repetition rate of about 1 kHz.

A turn-off circuit was devised to accelerate the charge carrier sweep-out from the base region by providing a negative V_{BE} of about 7 V to terminate the collector current from its steady state value. In this way, turn-off transients comparable in duration, or even shorter, than the turn-on transients could be obtained. Such a circuit was implemented by adding a negative pulser (a DEI model HV-1000N) to the circuit in figure 3. A Zener diode was used to set the negative voltage level. The passive components in these circuits need not have a high power rating, due to the very low duty cycle.

Figure 4 provides a diagram of the combined circuit, used primarily for capturing the turn-off transient, once steady I_C has been established by the positive base drive part. The two high voltage pulsers are timed by trigger signals from two channels of a delay trigger pulse generator, a Berkeley Nucleonics model 555. The output from the HV-1000N overcomes that from the HV-1000 sufficiently to activate the Zener diode, thus setting the negative base drive level. A low V_{BE} of about –0.6 V can be obtained by omitting the Zener diode. This circuit was constructed with low-power resistors and diodes for use at very low duty cycle only. Moreover, the model 555 was unable to gate the high voltage pulsers at duty cycles exceeding 10 percent. But using this somewhat elaborate setup, base voltage transition times, from positive to negative in less than 10 ns, could be achieved.

High Temperature Switching Data Overview

The data presented in table 1 are selected subsets of all such data taken at various temperatures, showing the amount of base drive needed to get acceptable switching at selected temperatures and load currents, for this SiC-based BJT. This data was taken using the constant current base drive mode and a reverse V_{BE} of about 7 V, primarily because it is easier to set the current to a given value. The values of currents indicated are their steady state values, reached typically in less than a microsecond. The table 1 data is taken from dynamic scope traces, such as reproduced in figure 5.

Several phenomena seen in this scope trace are worth a remark. Most interesting is the very low base charge storage time, as compared to that exhibited by similarly rated Si-based BJTs that we tested. Thus there is very little delay (~20 ns) between the end of

the positive base drive current pulse and the start of the collector current I_C drop. This suggests a low minority carrier lifetime in the base region. Of passing interest is the conspicuous linearity of the I_C drop, when a reverse base voltage (about 7 V in fig. 5) is applied to speed up the turn-off. Possibly due to capacitive and inductive effects, the rise in I_C is much slower than the 10 ns rise of the base-drive pulse and is as expected.

Figure 6 presents a comparative graphical analysis of the turn-on times as a function of the level of base drive, based on the 23 and 200 °C data groups in table 1. At any base drive level sufficient to achieve full turn-on, the turn-on transition time increases with increasing collector current, as expected. Also, to achieve the same rise time for a fixed collector current requires a higher base current pulse at the higher temperature. Thus increasing temperature has a slowing effect on the turn-on process. The I_B = 100 mA points could not be achieved for some of the curves in figure 6, for at this base drive level the BJT would not turn fully on under the indicated conditions. Indeed, much of this behavior is qualitatively similar to that of a Si-based transistor.

In the case of the turn-off time τ_{off}, the primary sensitivity is to the magnitude of the applied reverse V_{BE} and the magnitude of the steady-state collector current. The τ_{off} decreases slightly when going from 23 to 200 °C, or when decreasing the base-drive current. A simple example suffices to illustrate sensitivity to the applied reverse V_{BE}. At I_C = 4 A and I_B = 400 mA, the following 10 to 90 percent turn-off transition times τ_{off} were observed:

	23 °C	200 °C
τ_{off} for $V_{BE} = -7$ V:	77 ns	63 ns
τ_{off} for $V_{BE} = -0.6$ V:	148 ns	142 ns

Forced minority carrier sweep-out is seen to be quite effective, as it is with Si-based transistors. Very short τ_{off} can be obtained that way for the present device, because its junction breakdown V_{BE} is well in excess of 10 V.

At the 0.1 percent duty cycle used, no temperature rise above ambient of the BJT's case could be resolved from observations of the switching waveforms. The case itself was quite temperature stable, being fastened to a boron nitride hotplate to provide good heat conductivity and temperature control. For the on-off pulse shown in figure 5, the switching loss is about 60 µJ, the conduction loss is about 12 µJ and the base drive adds about 2 µJ, making for a total loss of about 74 µJ during the 500 ns wide pulse. For a 1 kHz repetition rate, the average power is thus only about 0.1 W

Switching and Conduction Losses

Occasionally the concern has been voiced that higher on-state conduction losses in SiC based, as compared to Si based, BJTs would be seriously adverse to their application as switches. To evaluate this, let us compare the conduction losses to switching losses expected for a waveform of switched square voltage V_0 and current I_0 pulses of width w, repeated with a period τ. The duty cycle D then is $D = w/\tau$.

Using an exponential approximation for turn-on and a linear approximation for turn-off, with respective time constants τ_{on} and τ_{off}, technically the switching losses are

$$E_{on} = 0.5\, I_0\, V_0\, \tau_{on} \ \text{(Joules)} \qquad (1)$$

and

$$E_{off} = (1/6)\, I_0\, V_0\, \tau_{off} \ \text{(Joules)} \qquad (2)$$

But for present purposes, it suffices to use the exponential approximation for both, writing

$$E_S = V_0\, I_0\, \tau_S \ \text{(Joules)} \qquad (3)$$

for the total switching loss. Note that $\tau_S = \tau_{S,10\text{-}90}/\ln 9$ in terms of the usually scope indicated 10 to 90 percent switching time $\tau_{S,10\text{-}90}$. Our BJT, switching say 4 A at 400 V in $\tau_{S,10\text{-}90}$ = 80 ns, thus has a switching loss of about 60 µJ for one pulse.

The conduction loss in one period is simply

$$E_C = I_0^2\, R_{CE,on}\, w, \ \text{(Joules)} \qquad (4)$$

where $R_{CE,on}$ is the saturated collector-to emitter on-resistance. This amounts to only about 12 µJ for the roughly 500 ns wide on-off pulse shown in figure 5. Division of E_S and E_C by τ then gives the average switching and conduction loss powers P_S and P_C. The ratio of these powers thus is

$$P_C/P_S = E_C/E_S = I_0\, R_{CE,on}\, w/(V_0\, \tau_S) \qquad (5)$$

To get a numerical feel for P_C/P_S in a practical application, assume a switching frequency of 200 kHz and a duty cycle of 0.5, giving w = 2.5 µs. From static curves in figure 1, $R_{CE,on} \approx 1.5\ \Omega$, but appeared to be less under fast pulse conditions. Again

assuming $\tau_{s,10\text{-}90}$ = 80 ns, Eq. 5 then gives P_C/P_S = 1.03. To be fair, a relatively smaller base drive power should be added to the P_C.

Clearly, the P_C/P_S depends on variable conditions. For example, going down to 100 kHz at the same duty cycle doubles the P_C/P_S. Also, a lower τ_s might be attainable with a lower load resistor (here 100 Ω). On the other hand, operation at higher frequency (smaller w) and higher voltage is also possible for the present device. Although the value of P_C/P_S is circumstantial, under the conditions of the present experiment, the results do not support the claim of necessarily unacceptably high conduction losses in SiC based BJTs.

Summary and Discussion

The data tables indicate that collector current turn-on transition times (10 to 90 percent) of 100 ns, or less, can be readily achieved with a 4 A current and a 100 Ω resistive load. This, however, requires a 400 mA base drive current step, at which the V_{BE} steadies out to roughly 10 V, with 4 A of collector current flowing. As expected, this turn-on time is sensitive to the base drive and the load currents, with only a slight sensitivity to temperature, from 23 to 200 °C. If the load current is lowered, then similar times can be obtained at a lower base drive.

An abrupt base turn-off was implemented by sending a negative voltage pulse to the base to overcome the positive base current pulse. Due to the low base charge storage time in this SiC device, there was no need to limit the reverse base current. The 7 V reverse pulse used was conservative, for the emitter junction reverse breakdown seemed to be above 10 V. This was sufficient to give collector current decay times of the same order as its rise times. Faster times may be possible, depending on the emitter-base breakdown characteristics. As expected, clamping the base voltage close to the emitter level greatly lengthens the turn-off time. Although zero level clamping is difficult with the pulsers, data points at about 0.6 V were obtained by omitting the Zener diode in figure 4. This about doubled the turn-off time.

The setup shown in figure 4 produces a collector current turn-off waveform that is nearly linear in time, whereas its turn-on waveform approximates closer to exponential (see fig. 5). This makes for a difference in the switching losses when calculating these from formulas to approximate the waveforms.

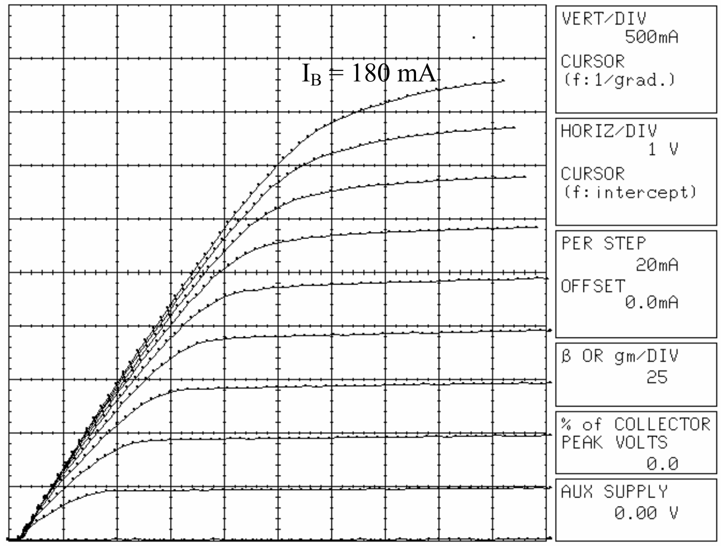
Although the tested device can switch up to at least 1.6 kW at 200 °C in a low duty cycle pulse mode, thermal conductance to case is expected to significantly reduce its capability at high duty cycle. With thermal resistance unknown, the estimation of junction temperature rise for a given average power dissipation in the device is problematic, at best.

Here the externally measured case temperature is thought to be a good measure of also the junction temperature, because of the very low duty cycle pulse mode and the rather low switching loss per on-off cycle.

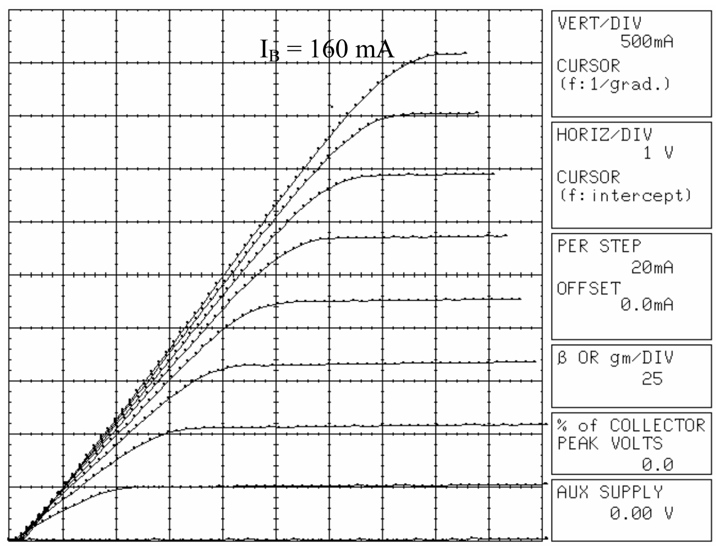
The ratio of conduction to switching losses was estimated, based on the observed collector current switching transition times and static curves. An estimate at 200 kHz and a 50 percent duty cycle shows that under practicable conditions the two losses can be comparable. Hence the evidence obtained does not support the occasionally voiced concern of necessarily unacceptably high conduction losses in SiC-based BJTs.

References

1. A.Q. Huang and B. Zhang, "Comparing SiC switching power devices: MOSFET, NPN transistor and GTO thyristor," *Solid-State Electronics 44*, pp. 325–340, 2000.
2. E. Danielsson et al., "Investigation of thermal properties in fabricated 4H-SiC high power bipolar transistors", *Solid-State Electronics 47*, pp. 639–644, 2003.
3. W. von Munch and P. Hoeck, "Silicon carbide bipolar transistor", *Solid State Electronics*, vol. 21, pp. 479–480, 1978.
4. J.W. Palmour et al., "6H-Silicon Carbide Power Devices for Aerospace Applications," in *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference*, pp. 1249–1254, August 1993, Atlanta, Georgia.
5. S.-H. Ryu et al., "1800 V NPN Bipolar Junction Transistors in 4H-SiC," *IEEE Electron Device Letters*, vol. 22, no. 3, pp. 124–126, March 2001.
6. J. Zhang, P. Alexandrov and J.H. Zhao, "High Power (500V-70A) and High Gain (44-47) 4H-SiC Bipolar Junction Transistors," *Materials Science Forum*, vols. 457–460, pp. 1149–1152, 2004.
7. S. Krishnaswami et al., "1000-V, 30-A 4H-SiC BJTs With High Current Gain," *IEEE Electron Device Letters*, vol. 26, no. 3, pp. 175–177, March 2005.
8. J.M. Niedra and G.E. Schwarze, "Static and Turn-on Switching Characteristics of 4H-Silicon Carbide SITs to 200 C," in *3rd International Energy Conversion Engineering Conference*, August 2005, San Francisco, California.



a. Observed at 200 °C.



b. Observed at 23 °C.

Figure 1.—Static I_C versus V_{CE} characteristics of the SiC-based BJT at selected I_B.

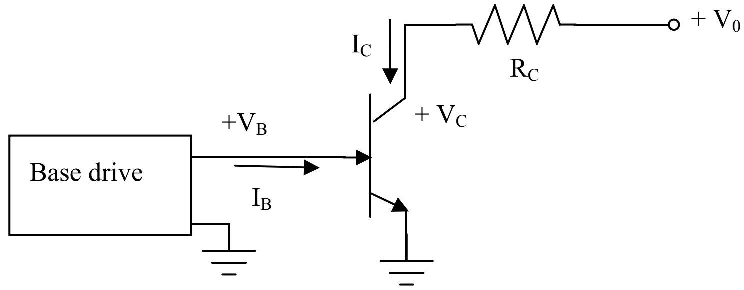


Figure 2.—Basic resistive load turn-on switching test circuit. Currents I_B and I_C are sensed by high-speed current transformers (Tektronix CT1 and CT2). Potential V_B is sensed by a 1 kΩ input impedance, fast-rise probe and potential V_C by a Tektronix 10X probe. R_C is a carbon composition resistor, normally set to 100 Ω.

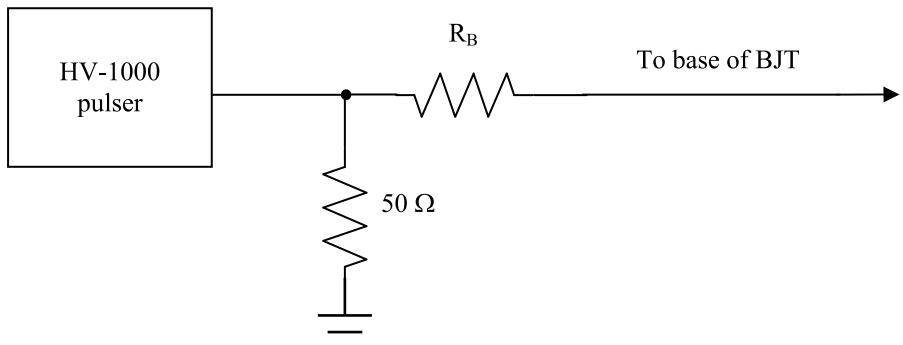


Figure 3.—Block circuit diagram for a pulsed constant current base drive. R_B values of 300 Ω to 1 kΩ were used.

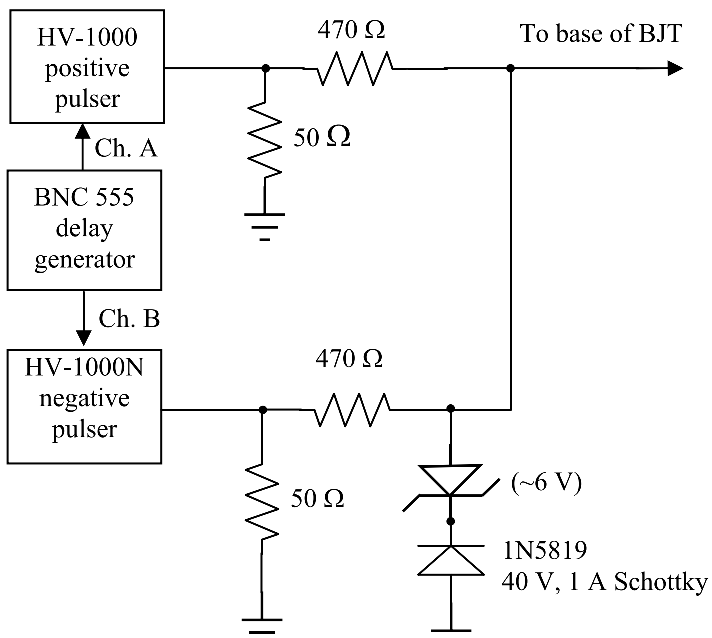


Figure 4.—Block circuit diagram of a pulsed constant-voltage base sweep-out drive added to the constant-current base drive of figure 2. The delay generator provides timed gating pulses, Channels A and B, to the positive and negative high voltage pulsers. The reverse V_{BE} is set by the Zener diode. A low reverse V_{BE} of about 0.6 V can be obtained by removing this diode.

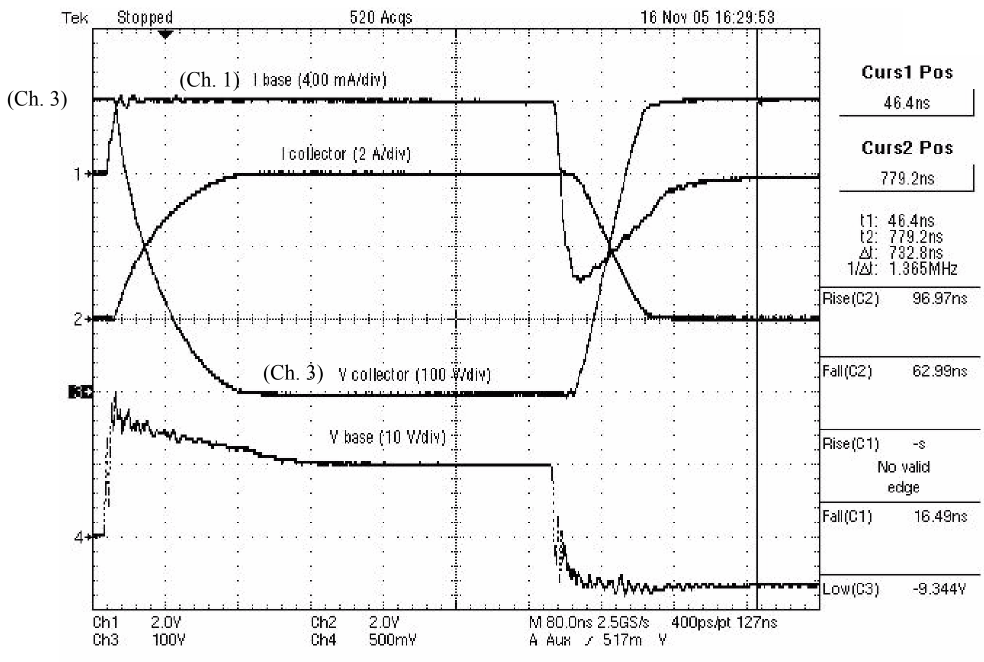


Figure 5.—Dynamics of the SiC-based BJT, switching 4 A into a 100 Ω load at 200 °C. The turn-on base pulse is 400 mA and the turn-off V_{BE} is about –7 V. The low base charge storage time is evident. Vertical scales applicable to the BJT are written above the traces and the time scale is 80 ns/div.

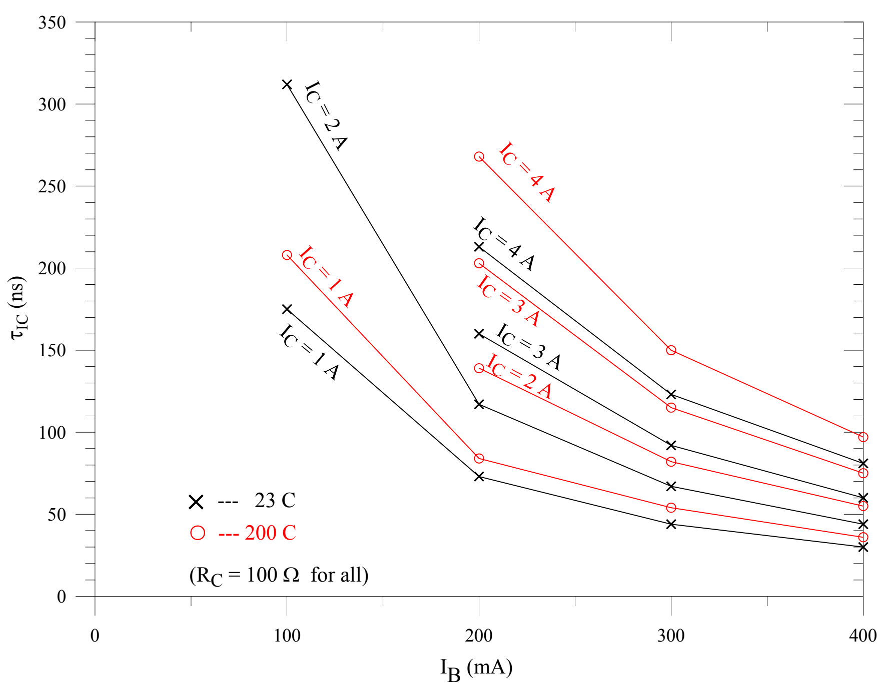


Figure 6.—Risetime of the collector current versus base drive current for selected values of the steady state collector current. Data are taken from the 23 and 200 °C groups in table 1 and only full turn-on points are plotted.

TABLE 1.—SWITCHING DATA, WITH A 100 Ω LOAD RESISTOR
AND –7 V BASE CHARGE SWEEP-OUT

Data at 23 °C:

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC, ON}$ (ns) (10 to 90 percent)	$\tau_{IC, OFF}$ (ns) (10 to 90 percent)
400.	4.0	402.	81.	77.
300.	“	402.	123.	76.
200.	“	402.	213.	71.
100.	“	>402	>500.	54., but NFO*
400.	3.0	303.	60.	67.
300.	“	303.	92.	66.
200.	“	303.	160.	65.
100.	“	>304.	>500.	55., but NFO*
400.	2.0	203.	44.	60.
300.	“	203.	67.	57.
200.	“	203.	117.	54.
100.	“	203.	312.	55.
400.	1.0	103.	30.	53.
300.	“	103.	44.	47.
200.	“	103.	73.	48.
100.	“	103.	175.	46.

Data at 100 °C:

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC, ON}$ (ns) (10 to 90 percent)	$\tau_{IC, OFF}$ (ns) (10 to 90 percent)
400.	4.0	402.	91.	61.
300.	“	402.	137.	61.
200.	“	402.	267.	60.
100.	“	>402.	>300.	(42., but NFO*)
400.	3.0	302.	70.	55.
300	“	302.	108.	54.
200.	“	302.	195.	52.
100.	“	>302.	>300.	(39., but NFO*)
400.	2.0	202.	52.	47.
300.	“	202.	76.	44.
200.	“	202.	136.	43.
100.	“	202.	>313.	40.
400.	1.0	101.	35.	54.
300.	“	101.	51.	47.
200.	“	101.	79.	43.
100.	“	103.	206.	42.

Data at 150 °C:

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC, ON}$ (ns) (10 to 90 percent)	$\tau_{IC, OFF}$ (ns) (10 to 90 percent)
400.	4.0	403.	94.	61.
300.	"	403.	146.	60.
200.	"	403.	274.	58.
400.	3.0	302.	72.	55.
300	"	302.	112.	53.
200.	"	302.	210.	51.
100.	"	>302.	>313.	38., but NFO*
400.	2.0	202.	54.	48.
300.	"	202.	81.	47.
200.	"	202.	138.	43.
100.	"	>202.	>314.	39., but NFO*
400.	1.0	102.	36.	58.
300.	"	102.	53.	51.
200.	"	102.	86.	43.
100.	"	102.	206.	44.

Data at 200 °C:

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC, ON}$ (ns) (10 to 90 percent)	$\tau_{IC, OFF}$ (ns) (10 to 90 percent)
400.	4.0	404.	97.	63.
300.	"	404.	150.	62.
200.	"	404.	268.	61.
400.	3.0	302.	75.	55.
300.	"	302.	115.	55.
200.	"	302.	203.	54.
100.	"	>302.	>315.	39., but NFO*
400.	2.0	202.	55.	50.
300.	"	202.	82.	47.
200.	"	202.	139.	46.
100.	"	>202.	>321.	39., but NFO*
400	1.0	102.	36.	63.
300.	"	102.	54.	53.
200.	"	102.	84.	51.
100.	"	104.	208.	39.

*NFO denotes that the BJT is not fully on, as a switch.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 2006	Technical Memorandum

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Static and Switching Characteristics of a 4H-SiC Based BJT to 200 °C	WBS 423799.03.01
6. AUTHOR(S)	
Janis M. Niedra and Gene E. Schwarze	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135–3191	E–15579

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
National Aeronautics and Space Administration Washington, DC 20546–0001	NASA TM—2006-214345

11. SUPPLEMENTARY NOTES

Prepared for the International Conference on High Temperature Electronics (HiTEC 2006) cosponsored by IMAPS, Sandia National Laboratories, Jet Propulsion Laboratory, and the Air Force Research Laboratory, WPAFB, Santa Fe, New Mexico, May 15–18, 2006. Janis M. Niedra, QSS Group, Inc., 21000 Brookpark Rd., Cleveland, Ohio 44135; and Gene E. Schwarze, NASA Glenn Research Center. Responsible person, Janis M. Niedra, organization code RPE, 216–433–6114.

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Unclassified - Unlimited Subject Category: 33 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.	

13. ABSTRACT ***(Maximum 200 words)***

Static curves and resistive load switching characteristics of a 600 V, 4 A rated, SiC-based NPN bipolar power transistor (BJT) were observed at selected temperatures from 23 to 200 °C. All testing was done in a pulse mode at low duty cycle (~0.1 percent). Turn-on was driven by an adjustable base current pulse and turn-off was accelerated by a negative base voltage pulse of either 7 or 0.6 V. Switching observations were done at base drive currents (I_B) up to 400 mA and collector currents (I_C) up to 4 A, using a 100 Ω non-inductive load. At I_B = 400 mA and I_C = 4 A, turn-on times typically varied from 81 to 97 ns, over temperatures from 23 to 200 °C. As expected, lowering the base drive greatly extended the turn-on time. Similarly, decreasing the load current to I_C = 1 A with I_B = 400 mA produced turn-on times as short as 30 ns. Over the 23 to 200 °C range, with I_B = 400 mA and I_C = 4 A, turn-off times were in the range of 61 to 77 ns with the 7 V sweep-out and 130 to 150 ns with the 0.6 V sweep-out. At a fixed temperature and I_C, the turn-off time decreased slightly with decreasing I_B, for I_B sufficient to still provide full turn-on. The ratio of conduction to switching losses is estimated, based on the observed I_C transition times and static curves. An estimate at 200 kHz and a 50 percent duty cycle shows that under practicable conditions the two losses can be comparable. Hence the evidence obtained does not support the occasionally voiced concern of necessarily unacceptably high conduction losses in SiC-based BJTs.

14. SUBJECT TERMS	15. NUMBER OF PAGES
SiC bipolar transistor; High temperature; Switching speedimes; Base charge sweep-out; Power loss	15
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	